Jan. 8, 1952 R. S. BAILEY 2,581,348

ANTENNA

Filed April 10, 1948 2 SHEETS—SHEET 1

Fig. 1.

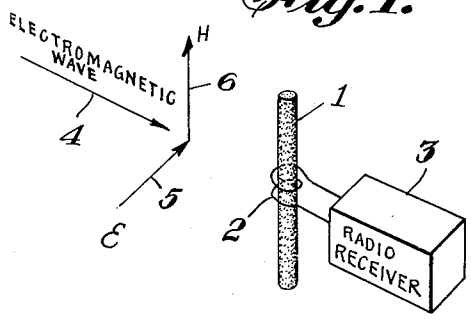


Fig. 3.

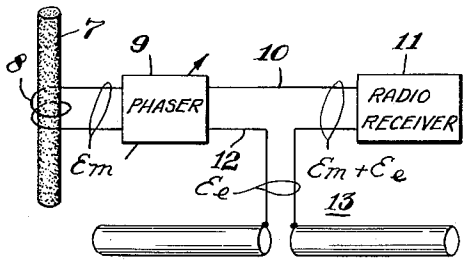


Fig. 2.

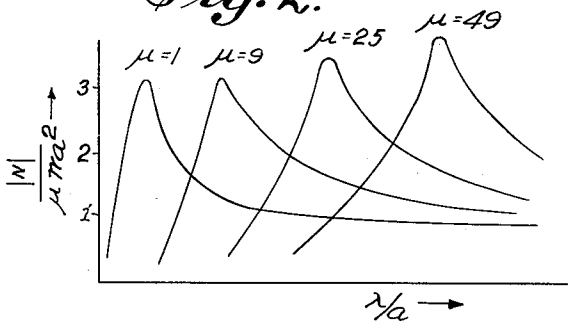


Fig. 4.

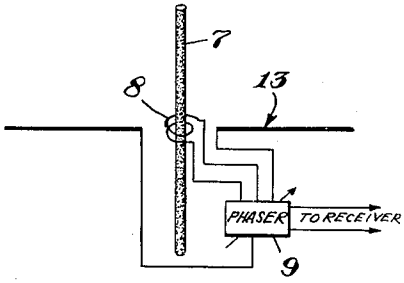


Fig. 6.

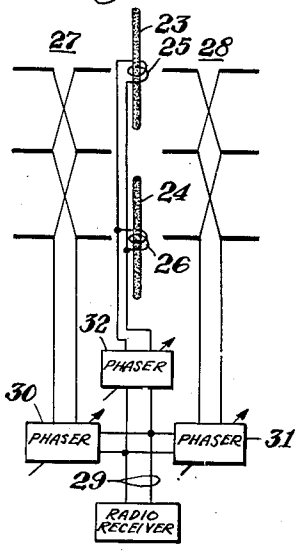
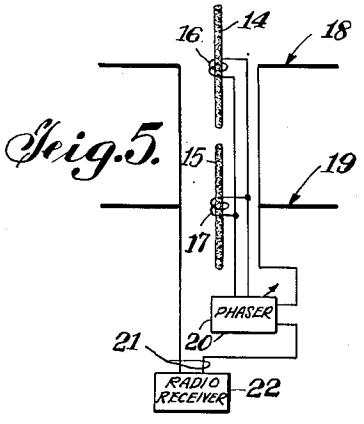


Fig. 5.



INVENTOR.
ROBERT S. BAILEY

BY

ATTORNEY

Jan. 8, 1952 R. S. BAILEY 2,581,348

ANTENNA

Filed April 10, 1948 2 SHEETS—SHEET 2

Fig. 7.

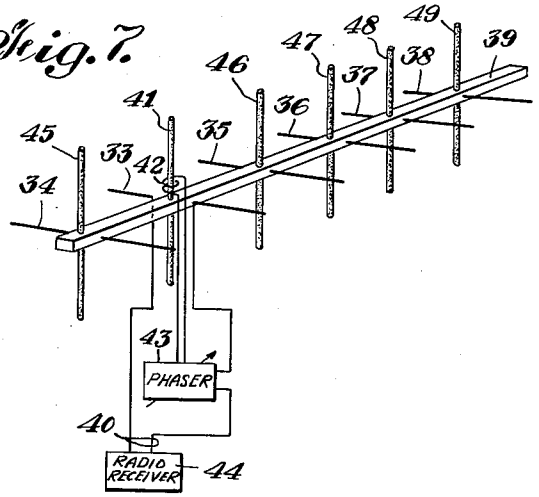


Fig. 8.

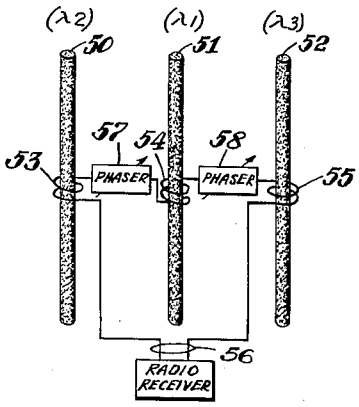


Fig. 9.

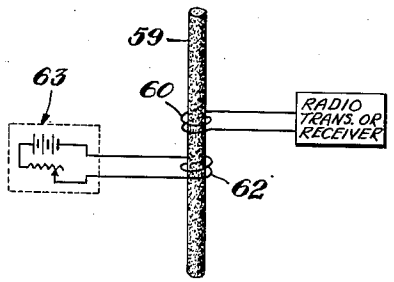
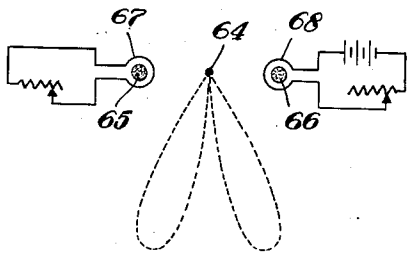


Fig. 10.



INVENTOR.
ROBERT S. BAILEY

BY

R. P. Morris

ATTORNEY

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UNITED STATES PATENT OFFICE

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ANTENNA

Robert S. Bailey, New York, N. Y., assignor to International Standard Electric Corporation, New York, N. Y., a corporation of Delaware

Application April 10, 1948, Serial No. 20,322

6 Claims. (Cl. 250—33.59)

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This invention relates to antennas, and more particularly it relates to antennas for efficient operation at very high frequencies over a broad band.

A principal object of the invention is to provide an antenna system which more efficiently utilizes the magnetic component of the radiation field.

Another object is to provide a receiving antenna wherein the pickup element is constituted of a magnetic member of predetermined permeability and permittivity per unit length, and is electromagnetically coupled to a radio receiver or the like.

Another object is to provide more efficient antenna array for broad frequency band operation.

A further object is to provide a novel combination of antenna elements, one element responding efficiently to the electric component of the radiation field, and another element responding efficiently to the magnetic component of the field.

A feature of the invention relates to a composite antenna array having elements which respond efficiently to magnetic components, and non-magnetic elements which respond efficiently to electric components of a radiation field.

Another feature relates to an array of magnetic antenna units and a cooperating array of electric antenna units, which are mutually disposed to provide an overall characteristic of precise directivity and broad frequency band response.

Another feature relates to an antenna comprised of a group of magnetic antenna units whose respective magnetic permeabilities are predetermined and chosen of different values correlated with respective predetermined frequencies so that the antenna has an overall characteristic of precise directivity and broad frequency band response.

A further feature relates to an improved broad frequency band antenna array which is particularly suitable for the reception of very high or ultra high frequencies.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood, by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a generalized diagram explanatory of the invention.

Fig. 2 is a series of graphs also explanatory of the invention.

Fig. 3 is a schematic diagram of a composite magnetic and electric antenna according to the invention.

Figs. 4, 5 and 6 are respective modifications of Fig. 3.

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Fig. 7 shows the invention as embodied in an antenna array of the reflector-director kind.

Fig. 8 shows an antenna array according to the invention, and especially designed for broad frequency band reception of horizontally polarized waves.

Fig. 9 shows how the magnetic characteristics of an antenna according to the invention, can be signal-controlled so as to vary its frequency sensitivity characteristics.

Fig. 10 shows the invention as embodied in a lobe switching system.

The present invention is based primarily on the fact that if a rod, preferably cylindrical in cross section, and composed of compacted finely comminuted magnetic particles, has a few turns of wire wound around the central region, it acts more efficiently with respect to very high frequency waves, than does the conventional non-magnetic or electric antenna. For example, referring to Fig. 1, there is shown a cylindrical rod 1, composed of compacted and cemented magnetic powder such as is conventionally used in high frequency tuning slugs and the like. Wound around the central region of the rod, are a few turns of wire 2, which can be connected to any suitable radio receiver 3. The arrow 4 represents an arriving wave having electric and magnetic components. The electric component being represented by the arrow 5, and the magnetic or magnetostatic component being represented by the arrow 6. These arrows, in accordance with well-known electromagnetic wave theory, are mutually perpendicular to each other. Preferably, although not necessarily, the rod 1 is disposed so as to be parallel to the magnetic component H of the arriving wave. It can be shown that for any given region of space where the rod 1 is located, the ratio of magnetic flux at a wave length λ, to the flux in the cylindrical rod of uniform cross-sectional radius "a" and magnetic permeability μ and permittivity K, in a magnetostatic field of unit intensity is

$$\frac{N}{\mu\pi a^2}=\frac{4}{\frac{(\mu\pi)^2a^1}{\lambda^2}\sqrt{K\mu}}\cdot\frac{J_1\left(\frac{2\pi a}{\lambda}\cdot\sqrt{K\mu}\right)}{\sqrt{g_0^2+f_0^2}}\cdot ei\epsilon_0 \quad (1)$$

wherein, ϵ_0 is the lag of the flux in the rod, behind the H of the incident wave; $a<\lambda$; and,

$$f_0=\sqrt{\frac{\mu}{K}}J_1\left(\frac{2\pi a\sqrt{\mu K}}{\lambda}\right)J_0\left(\frac{2\pi a}{\lambda}\right)-J_0\left(\frac{2\pi a\sqrt{\mu K}}{\lambda}\right)J_1\left(\frac{2\pi a}{\lambda}\right) \quad (2)$$

$$g_0=\sqrt{\frac{\mu}{K}}J_1\left(\frac{2\pi a\sqrt{\mu K}}{\lambda}\right)N_0\left(\frac{2\pi a}{\lambda}\right)-J_0\left(\frac{2\pi a\sqrt{\mu K}}{\lambda}\right)N_1\left(\frac{2\pi a}{\lambda}\right) \quad (3)$$

and tan $\epsilon_0 = f_0/g_0$; and J_1 and N_1 are the Bessel and Neuman functions. Also, the E. M. F. per turn N of wire around the rod is

$$\epsilon_M = \frac{2\pi}{\lambda}|N| \quad (4)$$

whereas the E. M. F. produced in the conventional non-magnetic or electric antenna is $\epsilon e = 2a$. Therefore the efficiency or ratio of the two types of antennas is

$$\epsilon_M/\epsilon_e = \tfrac{1}{2}\left(\frac{2\pi a\mu}{\lambda}\right)\left(\frac{|N|}{\pi a\mu^2}\right) = \frac{N|}{\lambda\mu} \quad (5)$$

It can be shown that the quantity $|N|/\mu a^2\pi$ varies with respect to μ and λ as represented by the four typical graphs in Fig. 2.

It will be seen therefore, that a magnetic antenna such as shown in Fig. 1 is critical as to frequency, magnetic permeability μ, and permittivity K, and presents a higher voltage output ϵ_m than the output ϵ_e of a similar electric antenna. The ratio ϵ_m/ϵ_e may reach a value of as much as 10 to 15 for particular combinations of μ, K, N, λ.

The present invention also proposes to provide a magnetic antenna comprised of an array for example of spaced units each consisting of a magnetic rod, the rods having different magnetic permeabilities, but with their permeabilities grouped around a center or mean permeability μ_c which coincides with the optimum ratio of ϵ_m/ϵ_e for the particular λ which is used. Since each antenna unit will have an E. M. F. gain of 10 to 15, or approximately 20 db, the net gain of such an array will be high, while at the same time providing a broad frequency band characteristic.

Since the E. M. F. from an electric antenna parallel to the electric vector is $\epsilon_e = 2\pi a$, the present invention also proposes an array consisting of crossed electric and magnetic antenna units. Such an array is shown in Fig. 3 and comprises a vertically disposed cylindrical rod **7** of the above described compacted magnetic powder, and around the central region of which is wound a few turns of a coupling coil **8** electrically insulated or spaced from rod **7**. The terminals of coil **8** are connected to the input of any well-known phase adjuster **9**, the output of which is connected by conductor **10** to a suitable radio receiver **11**. The other conductor **12** from phaser **9** is connected to the receiver in circuit with an electric antenna **13**, for example of the dipole kind, which is mounted preferably perpendicular to the rod **7**. The radius a_e of antenna **13** is so designed, and the phaser **9** is also so adjusted, that the E. M. F. ϵ_e from the electric antenna is in additive phase with respect to the E. M. F. ϵ_m from the magnetic antenna.

While Fig. 3 shows the two antennas mutually perpendicular and with the electric antenna adjacent one end of the magnetic antenna, preferably the two antennas are arranged in symmetrical crossed formation as schematically shown in Fig. 4.

It will be apparent to those skilled in the art that the array shown in Fig. 3 or Fig. 4 is substantially unidirectional and sensitive to waves arriving from only one of the two possible directions normal to the plane of the array.

If desired, more than one magnetic antenna unit can be employed. For example, there is shown in Fig. 5 a two-element array comprising a pair of aligned magnetic antenna units **14, 15**, with their respective central coupling coils **16, 17**. Mounted in crossed relation to unit **14** is an electric dipole **18**, and a similar electric dipole **19** is mounted in crossed relation with unit **17**. The several antenna units are connected, as shown, through a phase adjuster **20**, and thence by transmission line **21** to a suitable radio receiver **22**.

Fig. 6 shows an alternative array comprising a pair of magnetic antenna units **23, 24**, with their respective coupling coils **25, 26**. Mounted in crossed relation to the units **23, 24**, and on opposite sides thereof, are two arrays **27, 28**, of electric dipoles, each array consisting of three dipoles connected in cross-feed relation as shown, to the transmission line **29**. Suitable phase adjusters **30, 31, 32**, are provided between the magnetic units and the electric units so as to bring them into additive phase for application to the radio receiver.

Fig. 7 shows the invention embodied in an array of the "Yagi" kind. Such an antenna comprises the main dipole element **33**, with the parasitic reflector element **34**, and a plurality of director elements **35, 36, 37, 38**, all of which are supported from the common pole **39**. As is known in this kind of antenna, the rod **39** may be a metal tube or rod to which the reflector **34** and the directors **35—38** are also welded in parallel array. However, since the main element **33** is center driven, and is mechanically supported from rod **39**, it is electrically insulated so as to permit it to be connected to the transmission line **40**. Mounted in crossed relation to the unit **33** is a magnetic antenna unit **41** of compacted powdered magnetic material as above described, and having wound around its central region, but electrically insulated from rod **41**, the coupling coil **42** which is connected to line **40**, through phaser **43**, to bring the respective E. M. F's ϵ_m and ϵ_e into additive phase for application to the receiver **44**. Also supported on rod **39** in symmetrical crossed relation with respect to each of the elements **34, 35, 36, 37, 38**, are respective magnetic rods **45, 46, 47, 48, 49**, similar to rod **41**.

The invention is not limited to the combination of electric and magnetic antenna units. For example, advantage may be taken of the frequency selective response of the magnetic unit, to provide an array which is particularly efficient in connection with ultra high frequency horizontally polarized waves. Such an arrangement is shown in Fig. 8 and consists for example, of three rods **50, 51, 52**, of compacted powdered magnetic material, with their respective coupling coils **53, 54, 55**, which are connected to the transmission line **56** so as to be in additive phase. If desired, suitable phase adjusters **57, 58**, can be used to insure that the signals from the respective coils are brought into additive phase. As pointed out hereinabove, the magnetic rod antenna has a certain critical frequency response, depending upon its magnetic permeability and permittivity. Therefore, the antenna units **50, 51, 52**, are each designed with respective magnetic permeabilities and permittivities, so that each unit is selectively efficient in an optimum manner to a different frequency. For example, the unit **50** can be designed for a wave length $\lambda 2$; the unit **51** for a wave length $\lambda 1$; and the unit **52** for a wave length $\lambda 3$, and preferably so that $\lambda 1 - \lambda 2 = \lambda 3 - \lambda 2$. It will be understood of course, that while Fig. 8 shows an array of three magnetic antenna units, a greater number may be employed. In any such array it is preferred that one unit will be designed for optimum response at what may be termed a center wave length,

and the remaining units will be designed in pairs symmetrically disposed with relation to the center unit, but with each pair having an optimum response at a frequency equally spaced from the center frequency, and from the adjacent pair.

If desired, a single magnetic antenna unit can be employed and it can be connected to a suitable D. C. source so as to control its magnetic permeability. Thus as shown in Fig. 9, the magnetic rod 59 is provided with a coupling coil 60 for coupling the antenna to a radio set 61 which may be a radio transmitter or a radio receiver. Also wound around the antenna 59 is another coil 62 suitably insulated therefrom. Coil 62 is connected to a source 63 of adjustable direct current whereby the magnetic permeability of rod 59 can be adjusted so as to vary its optimum response for different frequency of impinging waves. If desired, the source 63 may be of the type which produces a saw-tooth wave of D. C. potential so as to cause the permeability of rod 59 to be varied progressively at a predetermined rate between two limits, thus likewise adjusting its optimum response with frequency. For example, source 63 may produce a D. C. wave which "sweeps" at a supersonic rate.

The arrangement of Fig. 9 can also be used to effect well-known lobe switching such as is employed in radar systems, guided landing systems and the like. Thus, as shown in Fig. 10, there may be provided an array of three antennas 64, 65, 66, which are excited and spaced to produce a predetermined directive radiation lobe, and the two side antennas can be keyed to cause the lobe to be moved to the right and left of a predetermined line. For a detailed description of such an antenna array, reference may be had to U. S. Patent No. 2,208,921 However, instead of employing three electric antennas as in said Patent No. 2,208,921 and keying the two side antennas on and off, the present invention uses for the side antennas 65, 66, magnetic rods such as described hereinabove, and each of these rods is provided with its respective coupling coil 67, 68, each of which is connected to a source of D. C. potential to control its magnetic permeability. By keying these D. C. sources at a predetermined rate, there results a switching of the resultant radiation lobe from one side to the other of the center line, as schematically represented in Fig. 10.

In all the foregoing embodiments the magnetic rod antenna should have a length approximately equal to one-half the wave length or a multiple thereof of the arriving waves.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention.

What is claimed is:

1. A composite antenna for very high frequency electromagnetic waves, comprising an antenna unit in the form of a rod of compacted powdered magnetic material which is selectively responsive to the magnetic components of an arriving electromagnetic wave, said rod being mounted parallel to the magnetic component of said wave, a non-magnetic antenna unit which is selectively responsive to the electric components of said wave, said non-magnetic unit being mounted parallel to the electric component of said wave, and phasing means to combine the responses of both said antenna units in additive phase.

2. An antenna according to claim 1 in which said magnetic unit is formed of a compacted powdered magnetic material having its magnetic permeability predetermined to produce an optimum response at the frequency of said wave.

3. An antenna according to claim 1 in which said magnetic unit has a coupling coil surrounding its central region and connected through a phase adjuster to a wave transmission line which connects with both units.

4. An antenna array comprising a plurality of rod-like magnetic antenna units each composed of compacted powdered magnetic material and mounted in linear alignment, and a plurality of non-magnetic antenna units symmetrically mounted with respect to the magnetic antenna units laterally disposed on either side of said magnetic units, first coupling means interconnecting the magnetic antenna units, second coupling means interconnecting the electric antenna units, and phasing means intercoupling said first and second coupling means in additive phase to a wave transmission line.

5. An antenna particularly suitable for radio reception, comprising an elongated rod of compacted magnetic powder having a permeability chosen so as to have optimum response at a selected frequency of electromagnetic waves incident thereon, a coupling coil surrounding the central region of said rod, a dipole mounted in perpendicularly intersecting relation with the said central region and having the arms of the dipole extending laterally on opposite sides of said rod, and phasing means to combine the responses of the said rod and said dipole.

6. An antenna array comprising a main antenna section consisting of an antenna unit in the form of a rod of compacted powdered magnetic material which is selectively responsive to an arriving electromagnetic wave, said rod being mounted parallel to the magnetic component of said wave, a non-magnetic antenna unit which is selectively responsive to the electronic components of said wave, said non-magnetic unit being mounted parallel to the electric component of said wave, and phasing means to combine the responses of both antenna units in additive phase, a parasitic reflector section mounted rearwardly of said main section and at least one director antenna section mounted in advance of said main antenna section, each of said parasitic and director sections consisting of a crossed electric antenna element and of a magnetic antenna element which latter is composed of compacted powdered magnetic material.

ROBERT S. BAILEY.

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